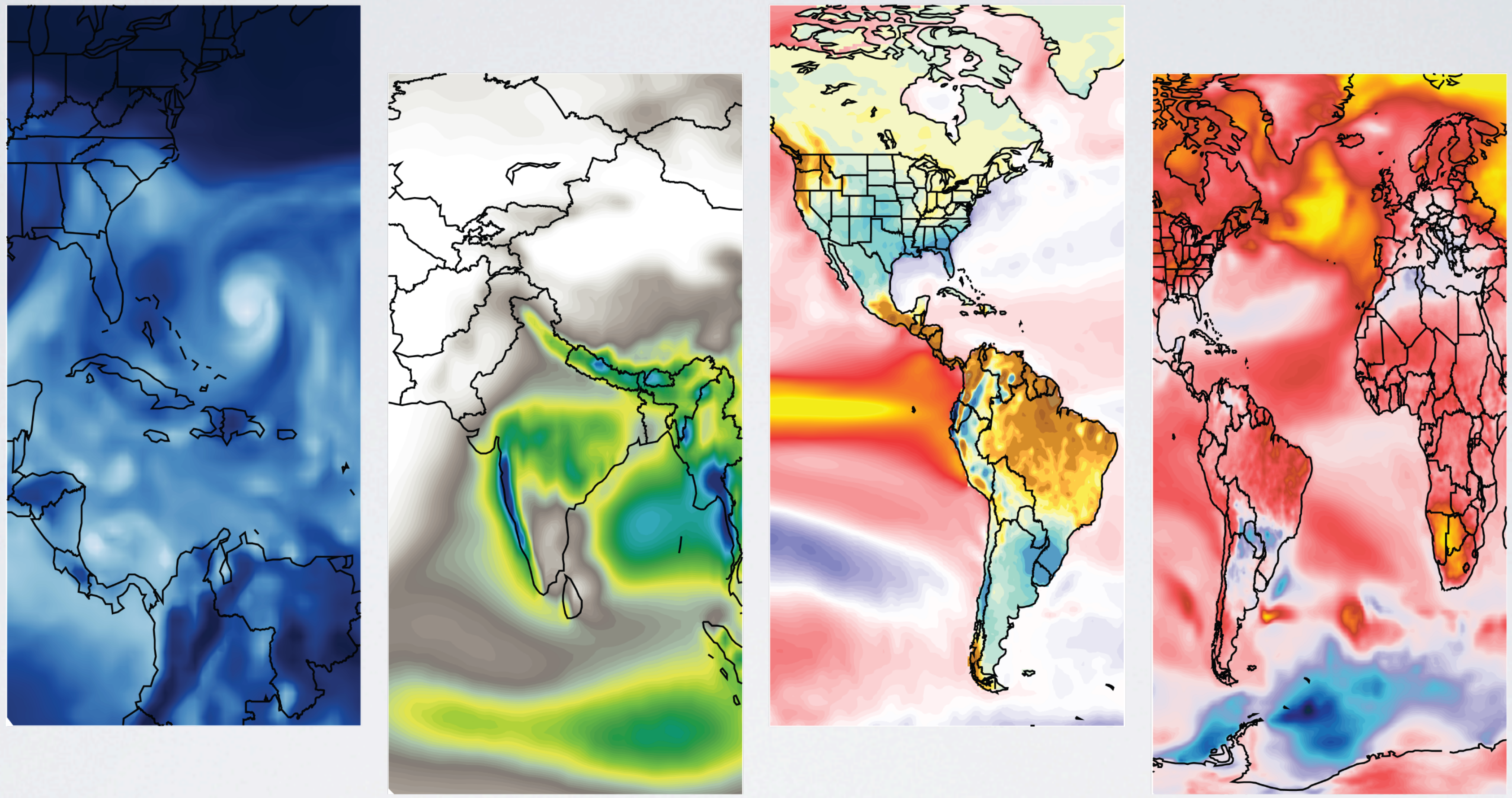
Seasonal to Decadal Predictions

Gabriel Vecchi – NOAA/GFDL



Introduction to basis, tools, limitations and ways of improving predictions

Why make predictions?

- Pragmatic reasons: skillful predictions help support decisions by providing glimpses of the future.
- Scientific reasons: prediction is a fundamental element of scientific method, providing tests to hypotheses underlying them.

Sources of & Limitations on Climate Predictability

Months to decades

hours to a month

Evolution of initial state of ocean/atmosphere.

Need good models and observations of present and past

Many decades to centuries

Climate response to forcing

(*e.g.*, CO_2, soot/dust, sun, volcanoes, land use)

need good models and estimates of forcing

Predictability has inherent limits: need to be probabilistic.

Elements of Climate Prediction System of Systems

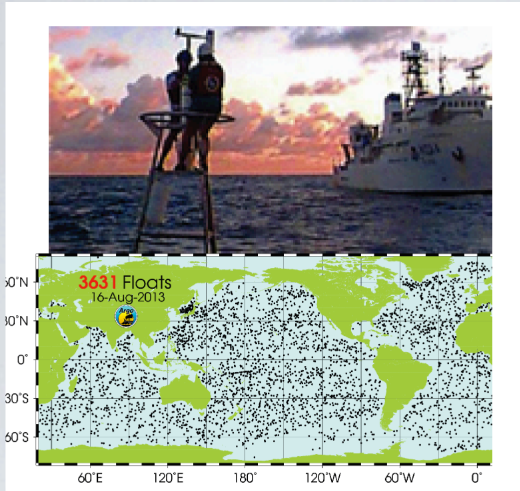
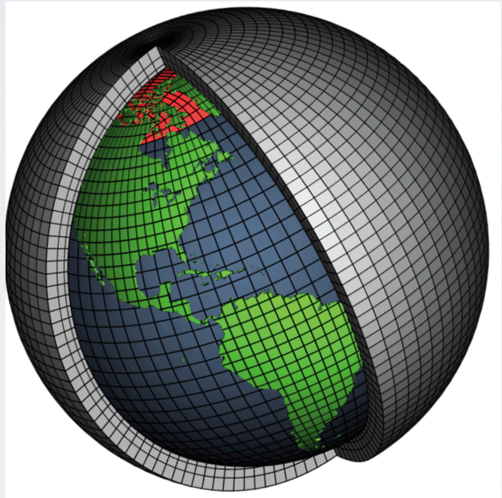
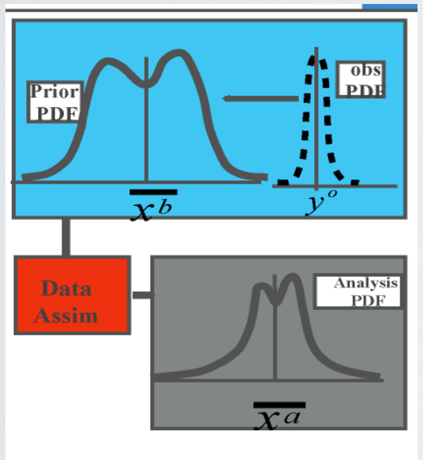


Image sources: NOAA/PMEL and Argo.ucsd.edu

Global climate observing system: Sparse observations of many quantities across globe.



Dynamical modeling system: Allows forward integration from present state, including expected changes in radiative forcing.



Data assimilation system: Combines sparse observations with model, to estimate present state. Usually based on dynamical model.

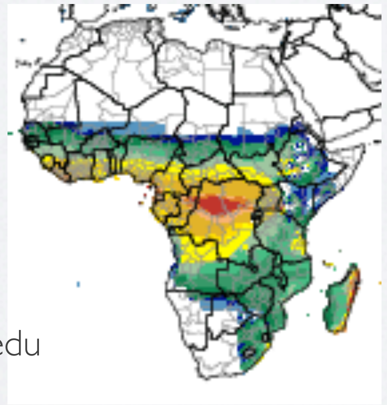
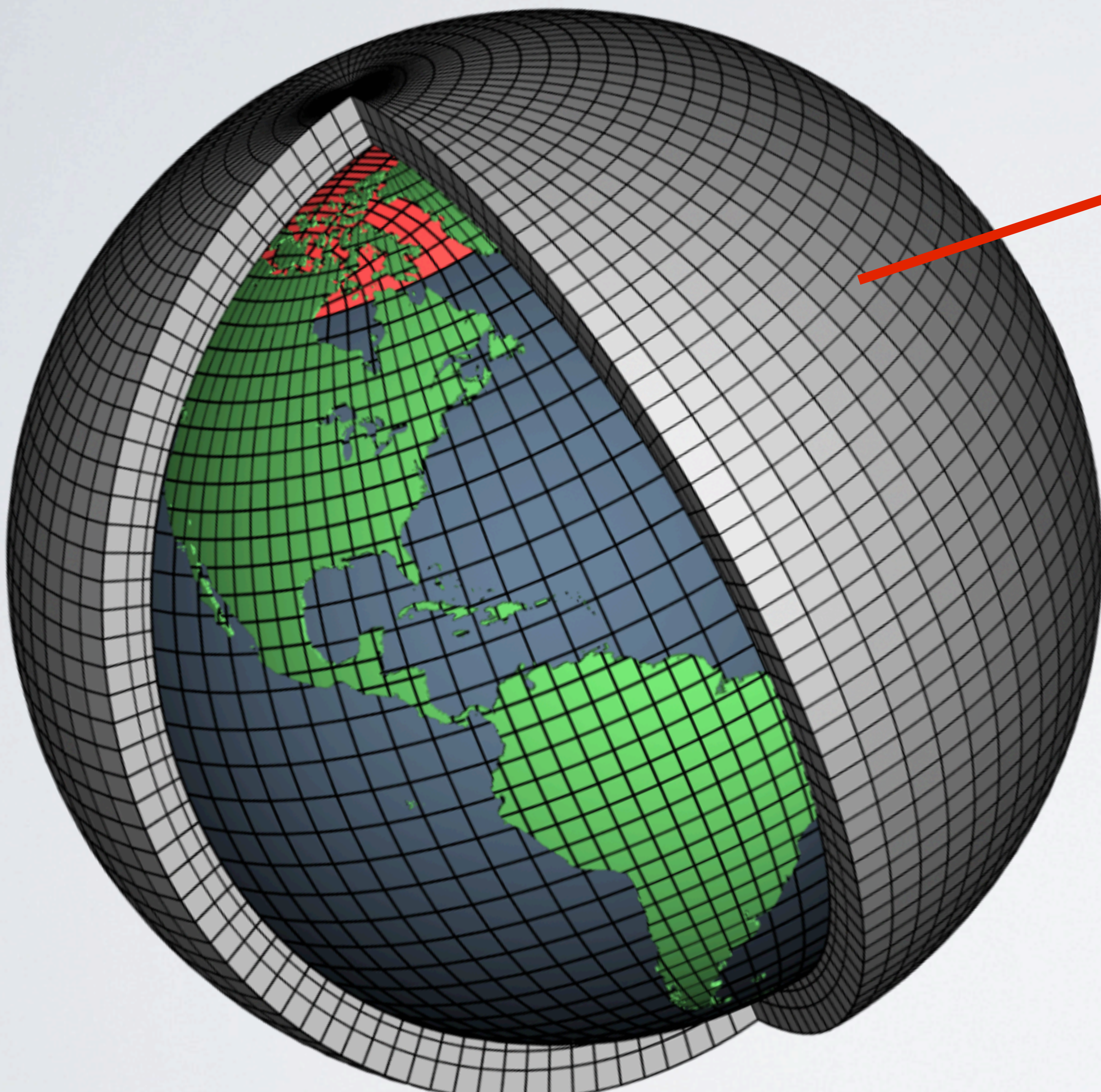


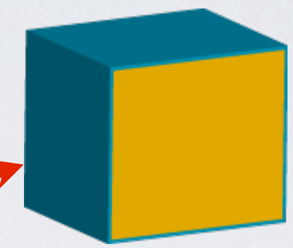
Image source: http://iridl.ldeo.columbia.edu

Analysis and dissemination system: Take output from predictions and produce "useful" information, communicate predictions.

Global dynamical model:

Mathematical representation of processes controlling ocean, atmosphere, land and ice system (and their interactions)





In each grid cell:

Resolved processes:

- conserve momentum ($F=m \cdot a$)
- onserve mass & energy (radiation, latent, etc...)
- account for changes in composition

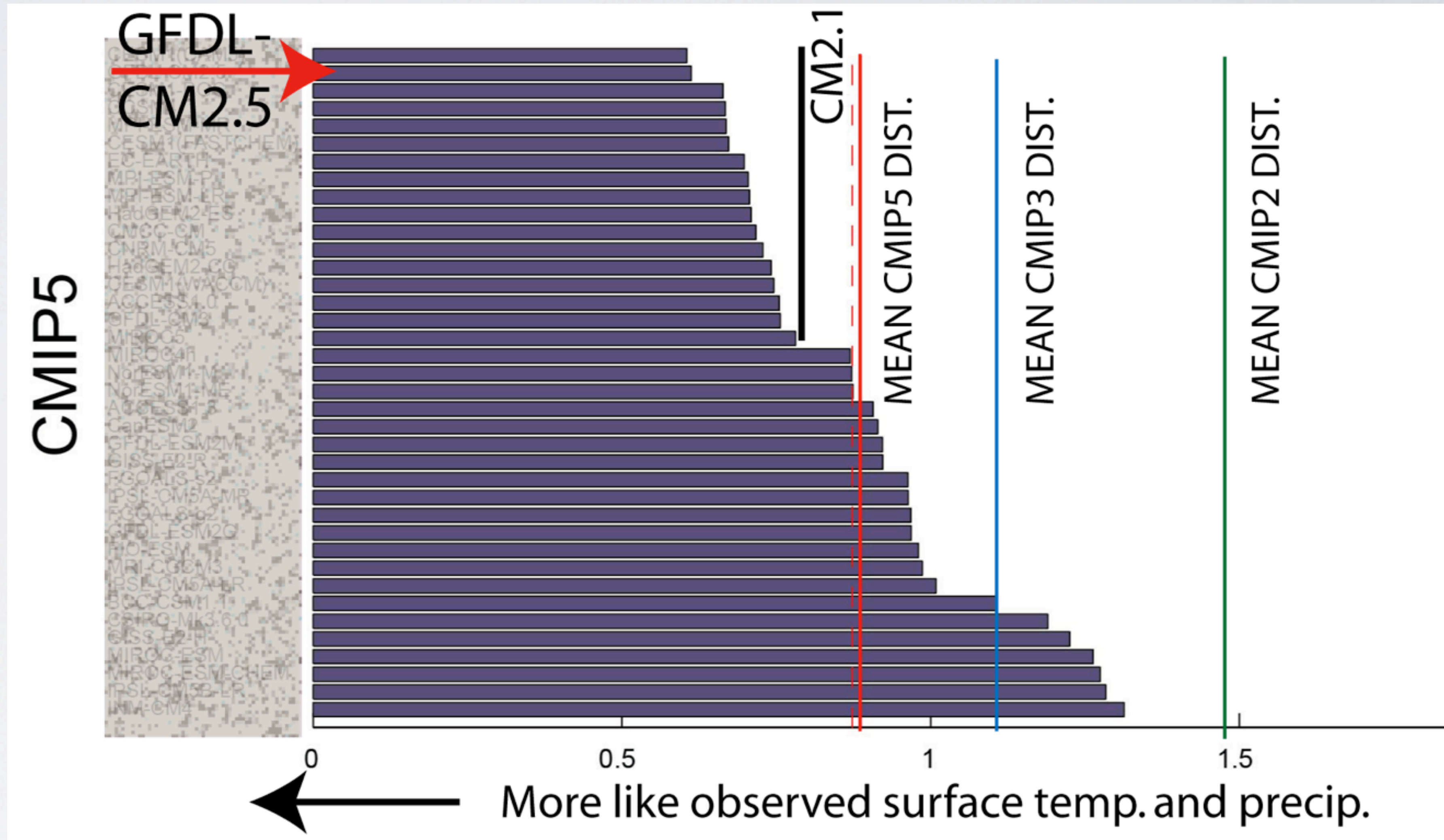
Parameterized processes:

- spatial/temporal resolution or understanding limit explicit solution.
- e.g., clouds, convection, etc.
- key to much of uncertainty

"Initialize" to observationally-constrained estimate of present state.
"Force" with solar radiation, structure of continents, land use and atmospheric composition (CO_2, O_3, aerosols, volcanoes, etc.)

High-resolution GFDL climate model (CM2.5) produces one of best global surface climate simulations of present model generation

Faster computer (GAEA) allows improved resolution that translates into significantly reduced biases in CM2.5 relative to CM2.1



Knutti et al. (2013)

CM2.5 described in Delworth et al. (2012) and companion papers

Sources of Forecast Uncertainty

- Inherent predictability limits: (depends on phenomenon and timescale generally leads to random errors; even "best possible" prediction system not perfect, with possibility of large failures at some point.
- Potentially predictable variations
- Observations (& Assimilation System)
  - sparse data coverage, inhomogeneity
- Forcings:
  - future CO_2, dust, sun, volcanoes unknown to some degree
- Models:
  - Systematic errors, inability to represent processes & phenomena
- Errors in analysis and communication

Dealing with Forecast Uncertainty

- Learn to live with irreducible uncertainties.

- "Noise" or natural variations:

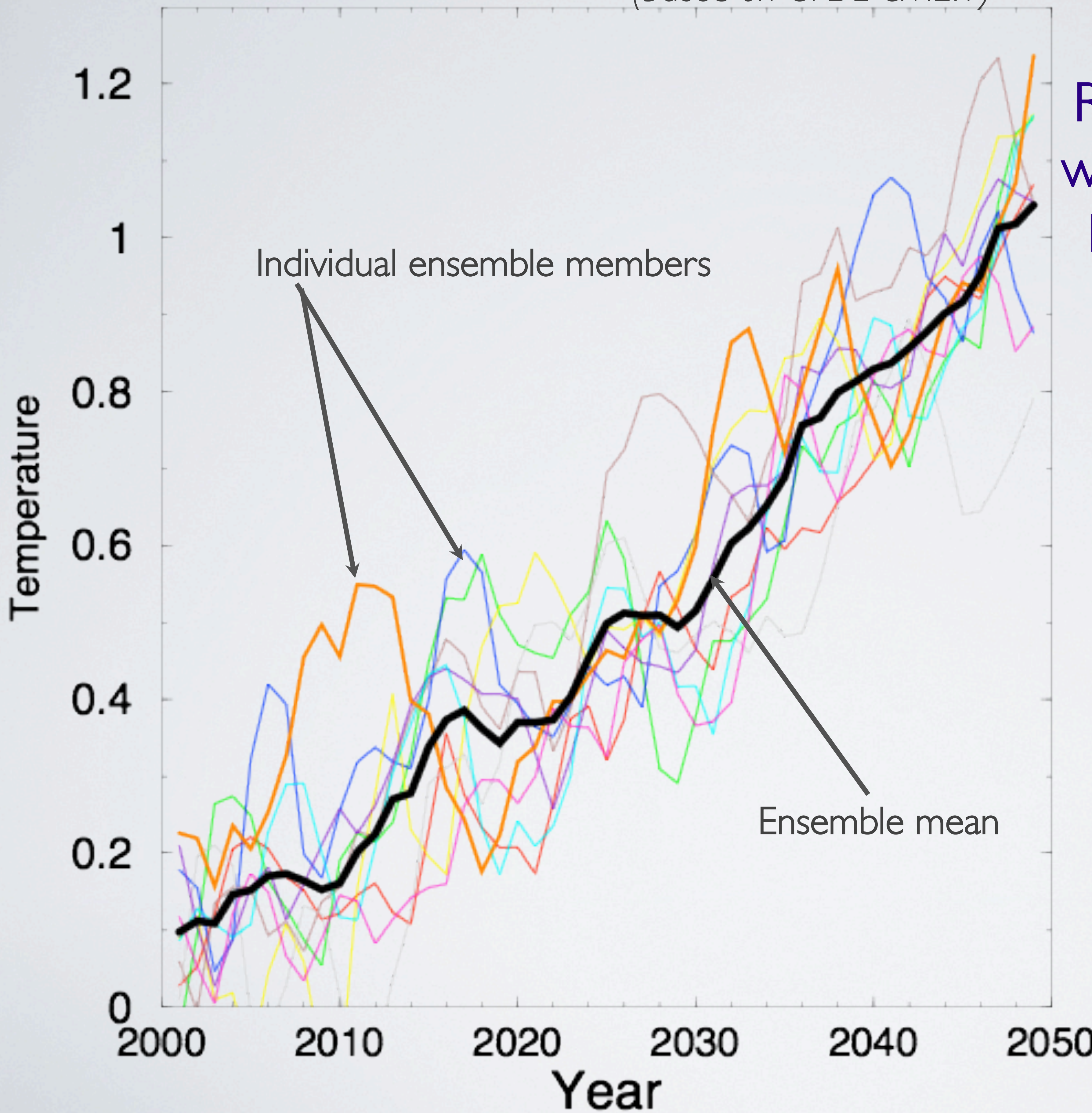
  Some unpredictable: probe noise via "single-model ensembles", parallel experiments with slight perturbations to initial state.

  Some may be predictable: start model close to present state of world

- Systematic model errors ("biases"):
  - Improve model:
    - Enhanced comprehensiveness
    - Increased resolution
    - Better parameterizations (things not explicitly represented)
  - Adjust for biases during and/or after forecast
  - "Wisdom of crowds" – some errors are different for different models, multi-model ensemble

Simulated Atlantic Sea Surface Temperature shows impact of climate variability

(based on GFDL CM2.1)



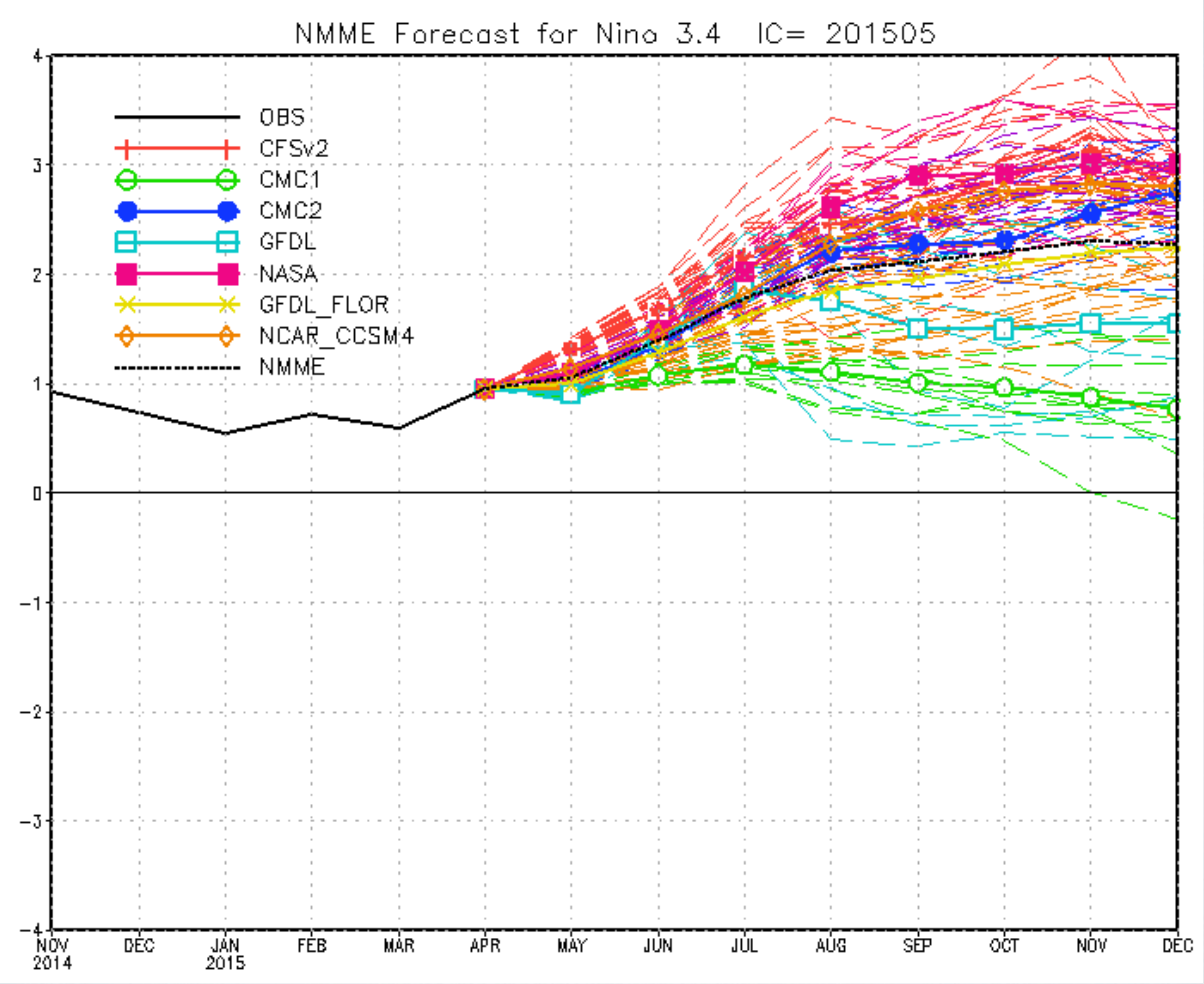
Radiative forcing leads to warming, but interspersed by variations in any one of the "equally likely" ensembles.

Can we predict the trajectory of Atlantic temperatures over the next several decades?

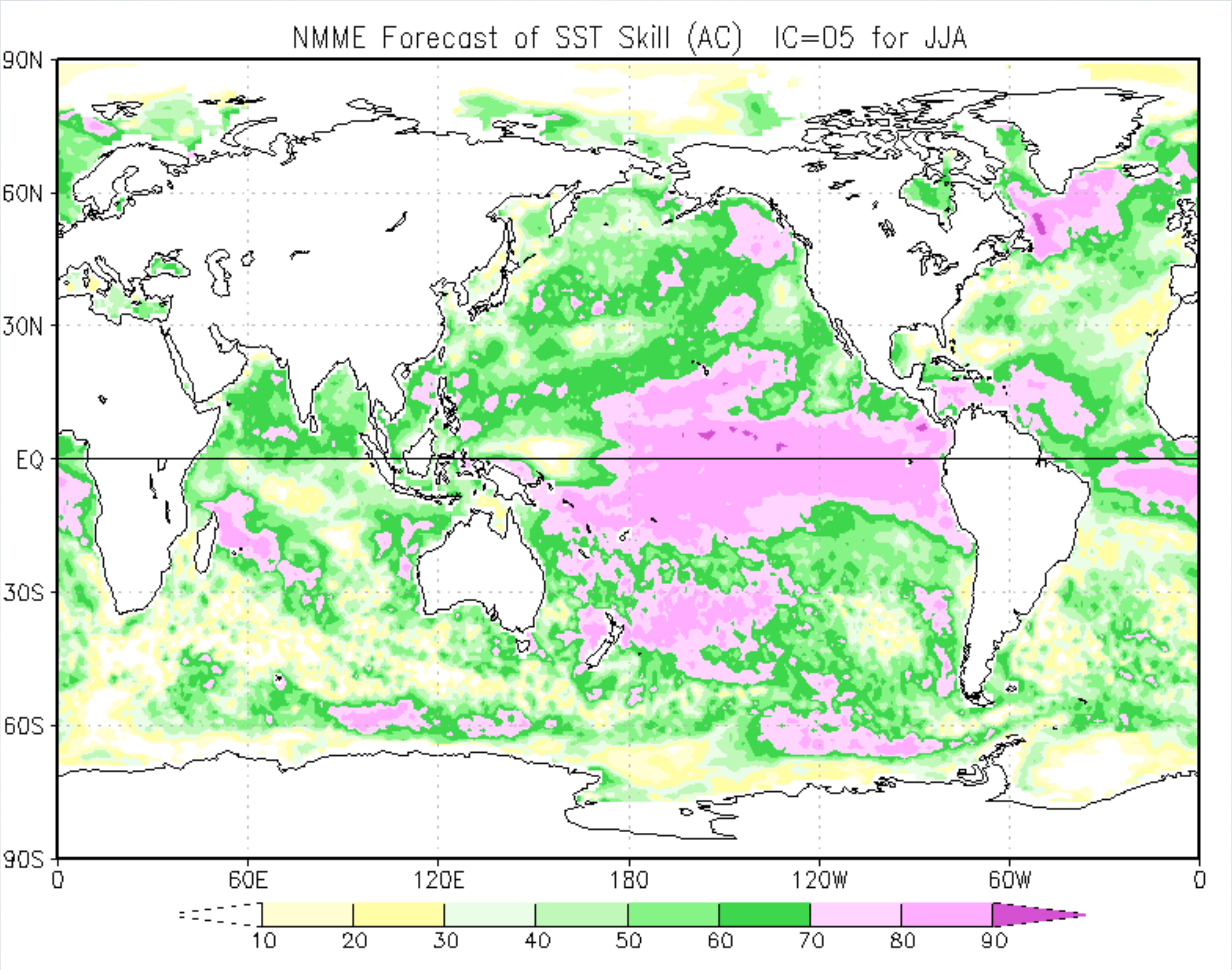
How about hurricane activity?

Slide: Tom Delworth (GFDL)

Predicted NIÑO3.4 SSTA showing inter-model ("epistemic") and inter-ensemble ("aleatory")

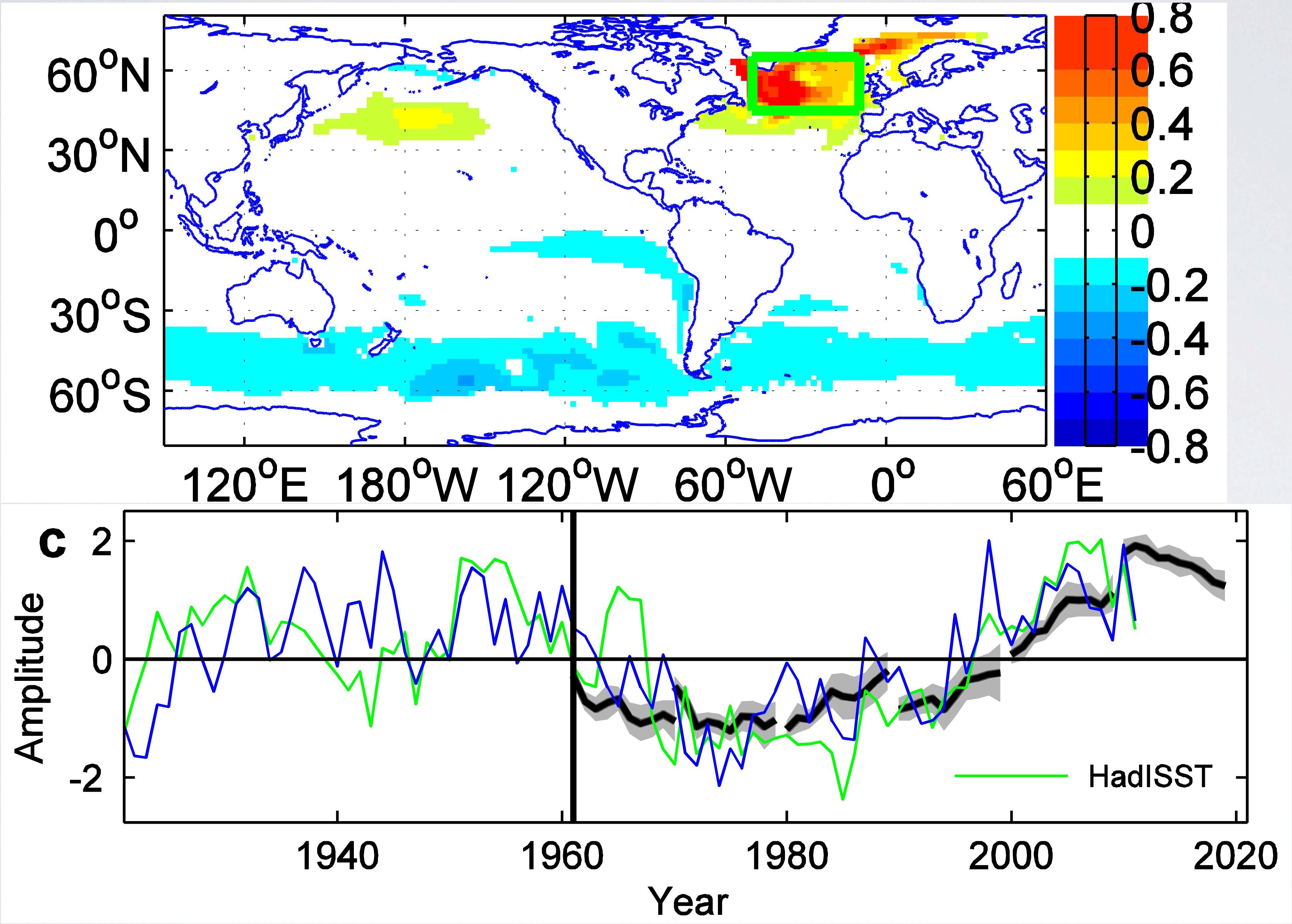


Tropical Pacific and a number of other regions highly predictable (sometimes) on year-to-year timescales



Aspects of Internal Variability Can be Source of Predictability: Initialization Enables Prediction of 1994-5 Shift in Sub-Polar Gyre

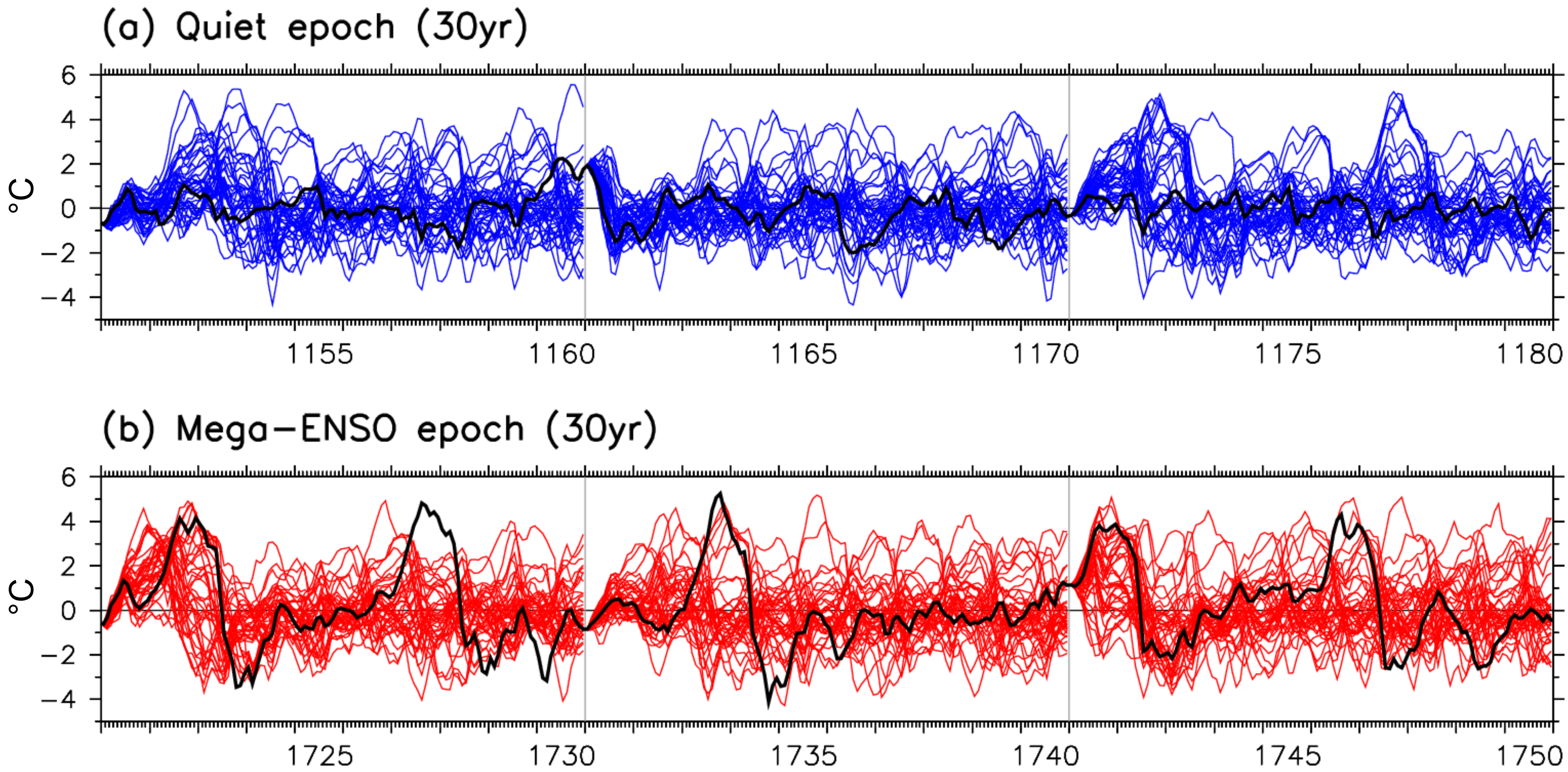
Most Predictable Sea Surface Temperature Pattern 2-9 years in advance



Yang et al. (2013)

“Perfect” ensemble reforecasts indicate inherent multi-year unpredictability

This is what *perfect* probabilistic forecasts look like!
(perfect model, near-perfect initial conditions, 40 members)



Wittenberg et al. (2014, J. Clim.)

Model resolution

- Increasing model resolution can, in principle, improve predictions by:
  - allowing parameterized some processes become resolved
  - represent features (e.g., topography) better
  - resolve new phenomena (e.g., eddies, storms)

- Increasing model resolution can complicate by:
  - increasing run cost (2x spatial resolution -> ~8x cost)
  - increasing data volume
  - analysis more difficult
  - initialization not always scale independent
  - "prettier" creates – possibly false – impression of "better"

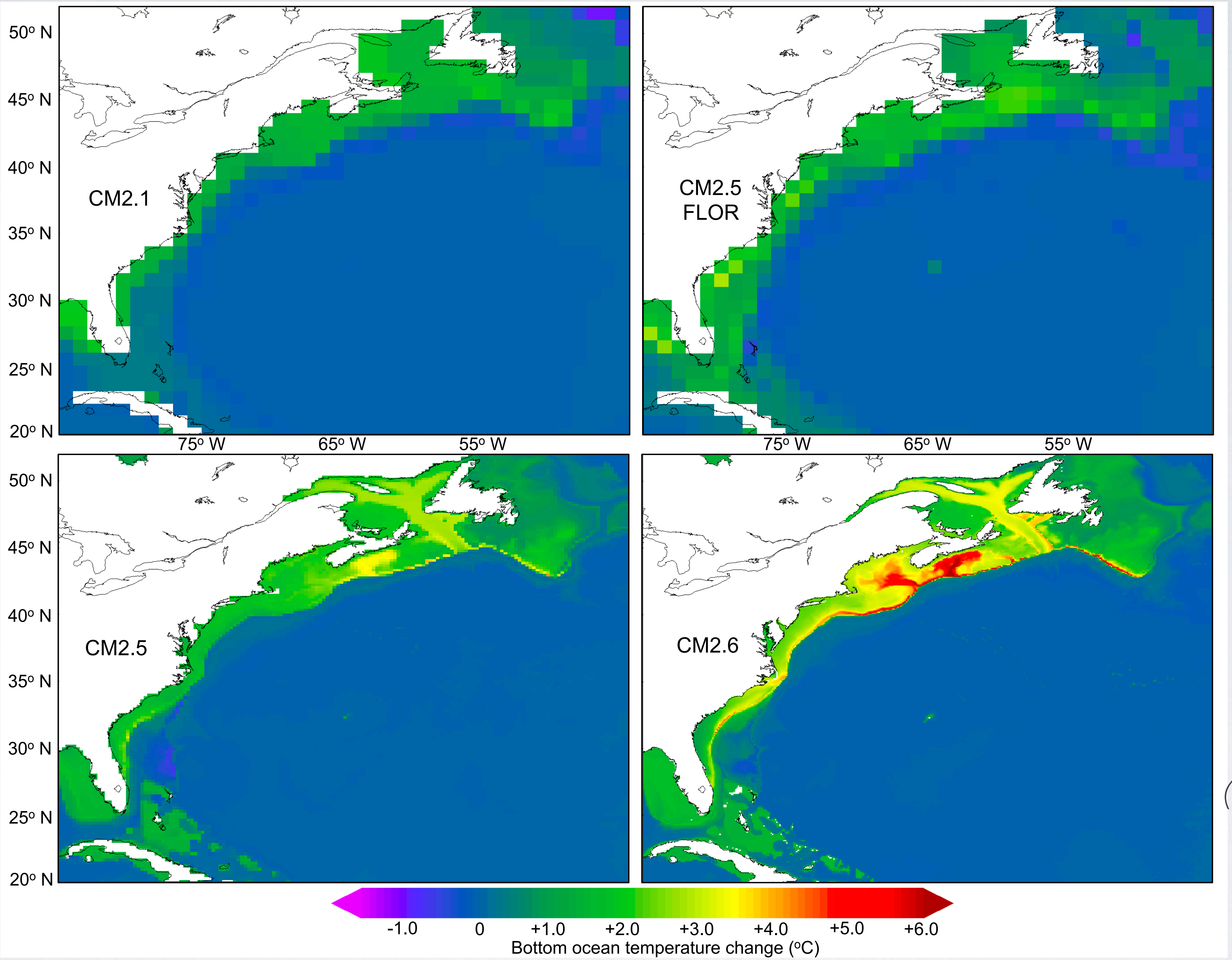
Increasing model resolution can lead to different answers: e.g., Atlantic response to $2xCO_2$ (Saba et al. submitted)

CM2.1

1° ocn.
200km atm.
(Delworth et al. 2006)

FLOR

1° ocn.
50km atm.
(Vecchi et al. 2014)



CM2.5

0.25° ocn.
50km atm.
(Delworth et al. 2012)

CM2.6

0.1° ocn.
50km atm.
(Delworth et al. 2012)

Bottom ocean temp response to 2xCO2 (K)

GFDL FLOR: Experimental high-resolution coupled seasonal to decadal prediction system

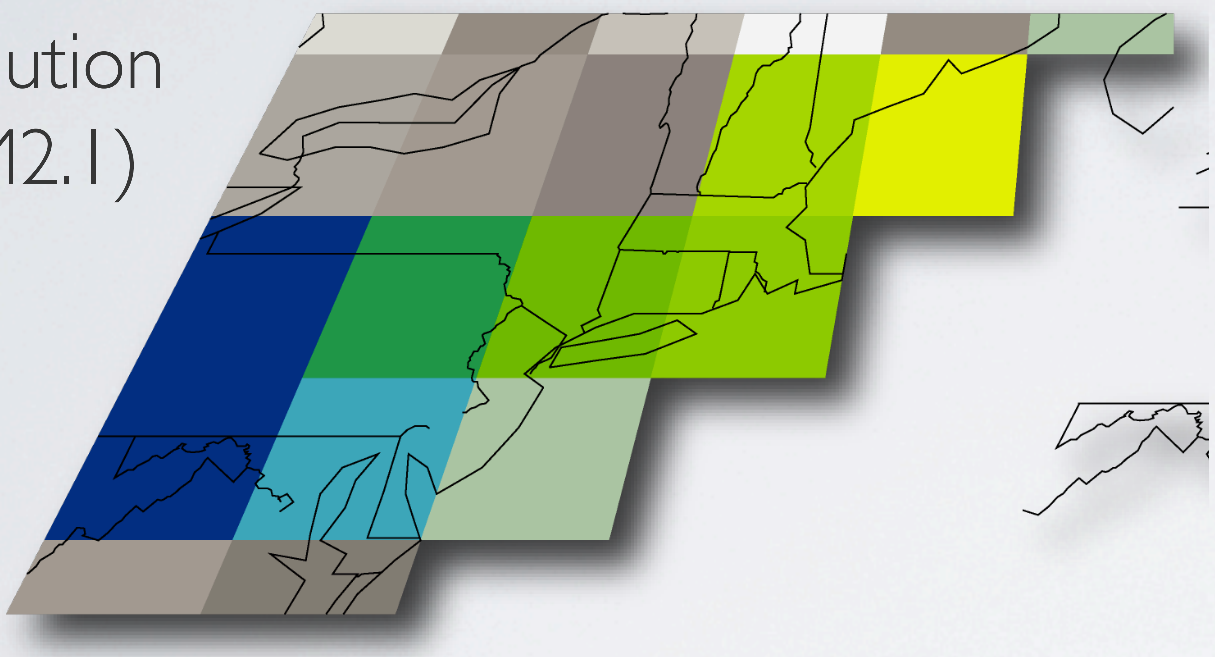
Goal: Build a seasonal to decadal forecasting system to:

Yield improved forecasts of large-scale climate

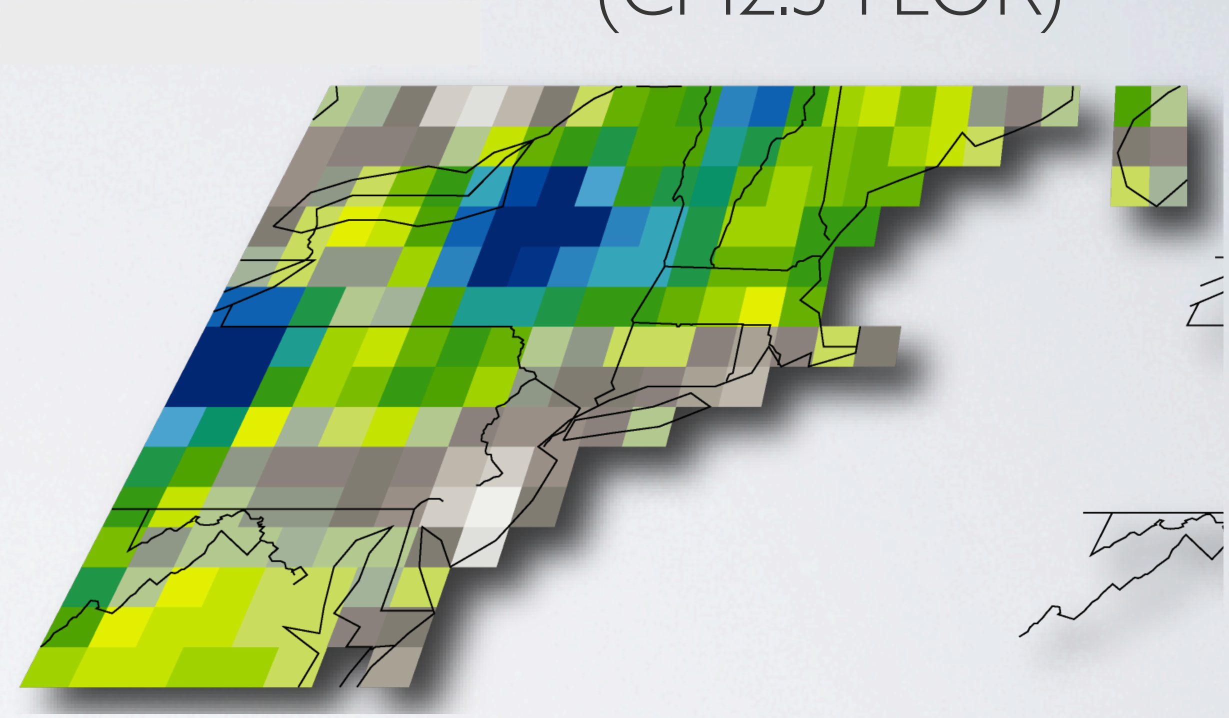
Enable forecasts of regional climate and extremes

Precipitation in Northeast USA

Medium resolution (CM2.1)



High resolution (CM2.5-FLOR)



Delworth et al. (2012), Vecchi et al. (2014)

Modified version of CM2.5 (Delworth et al. 2012):

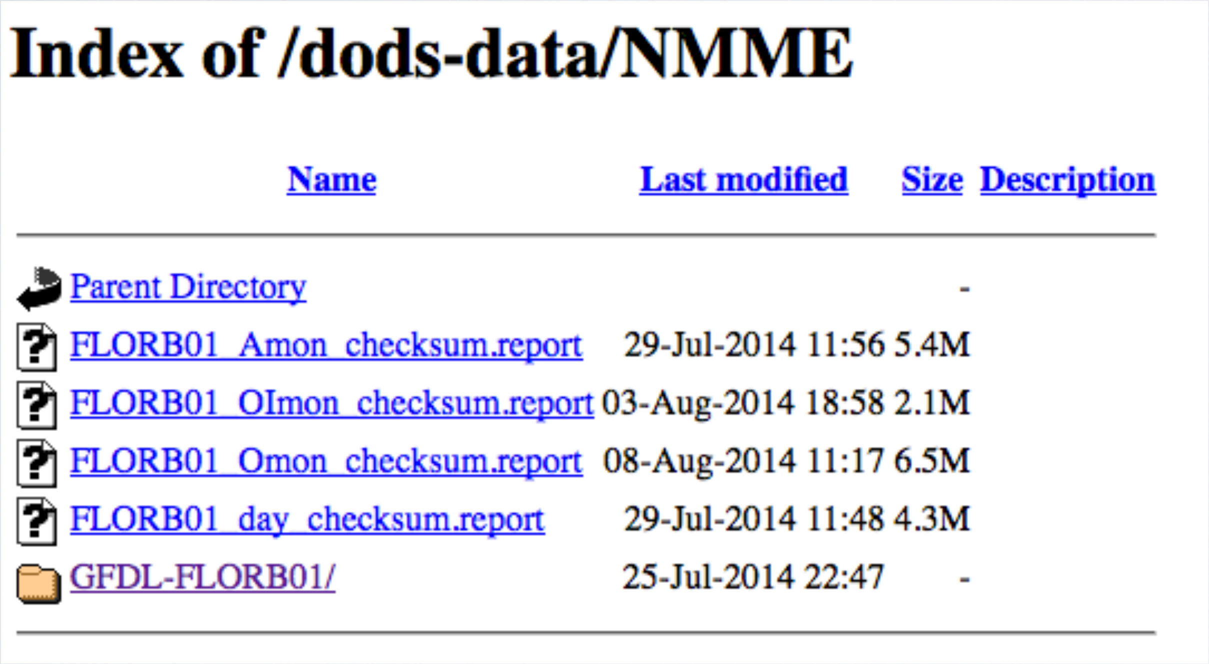
- 50km cubed-sphere atmosphere
- 1° ocean/sea ice (low res enables prediction work)

~15-18 years per day. Multi-century integrations. 4,700+ model-years of experimental seasonal predictions completed and being analyzed.

FLOR forecast data freely available from GFDL and NMME – model public

4700+ years of forecast data freely available
(33 years, 12 start months, 12 ensembles)
http://nomads.gfdl.noaa.gov/dods-data/NMME/

CM2.5 and FLOR models public
http://www.gfdl.noaa.gov/cm2-5-and-flor



Index of /dods-data/NMME

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FLORB01_Amon_checksum.report	29-Jul-2014 11:56	5.4M	
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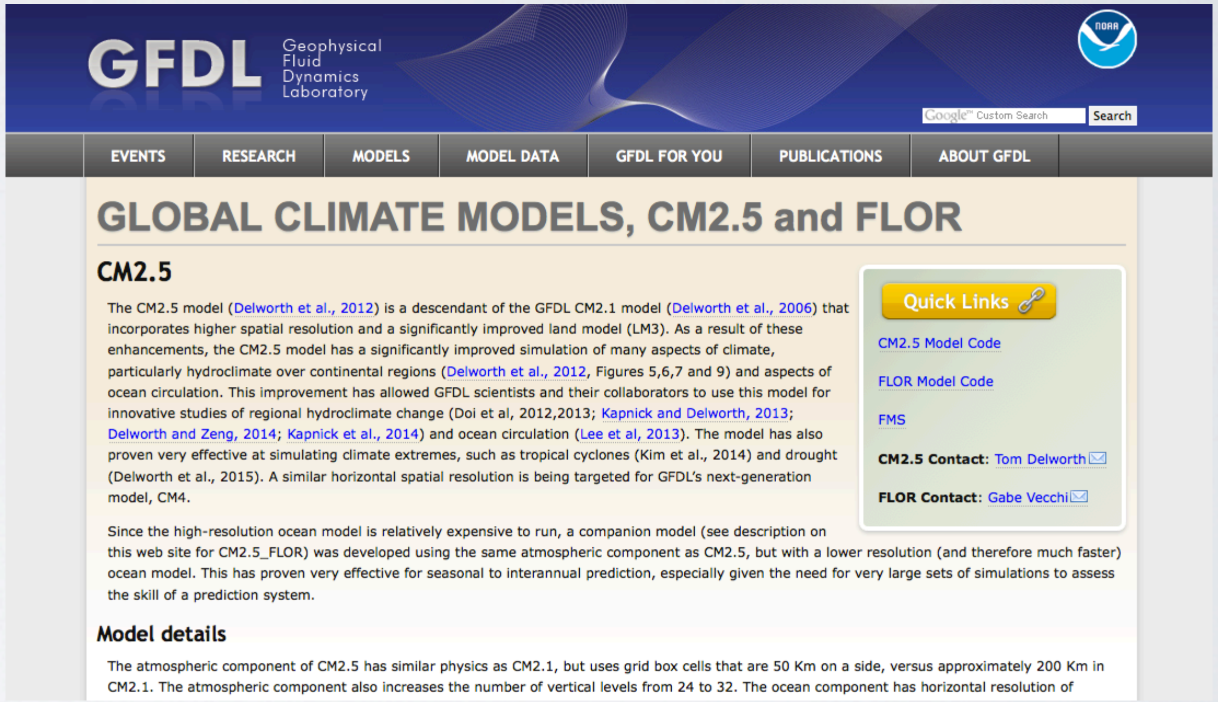
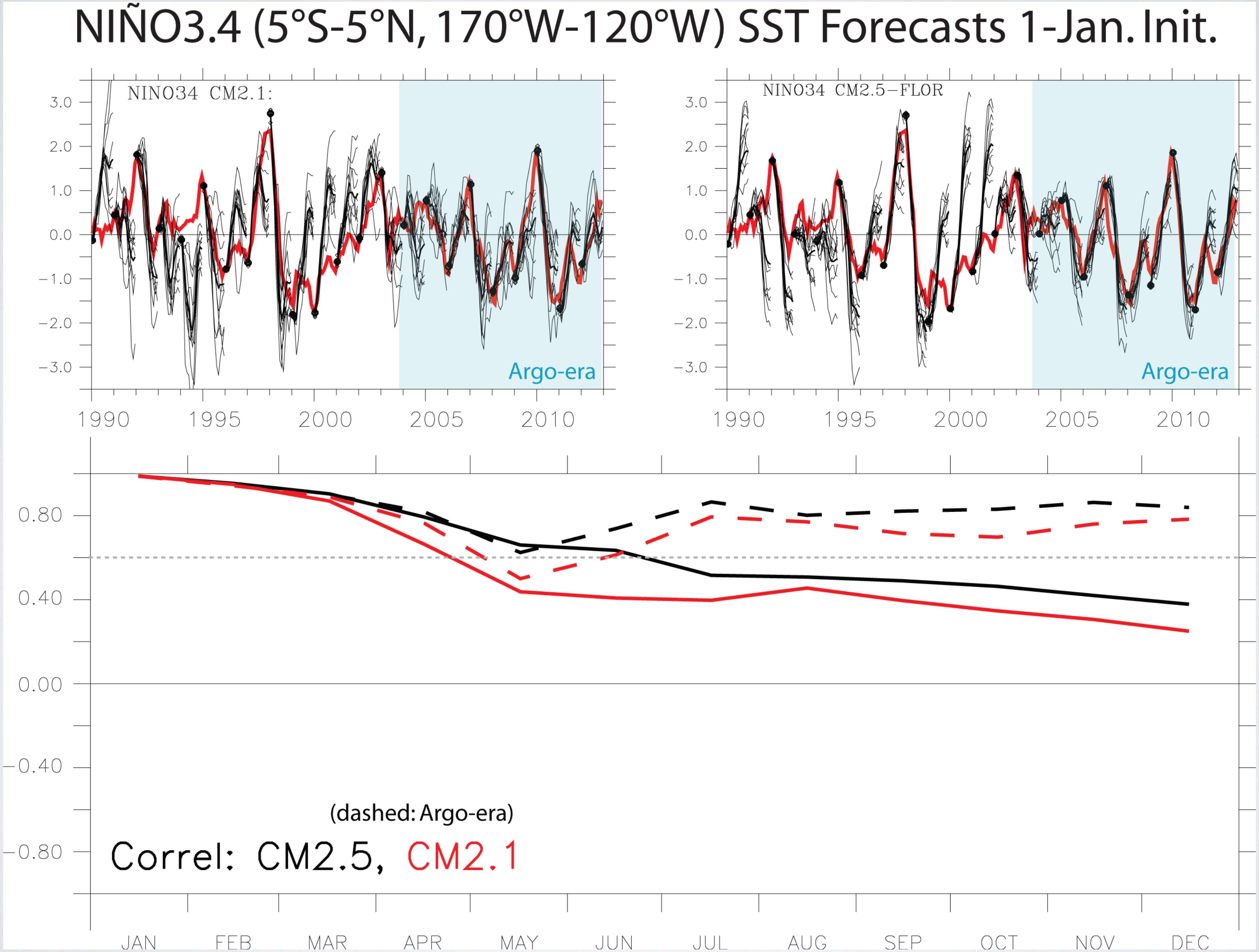


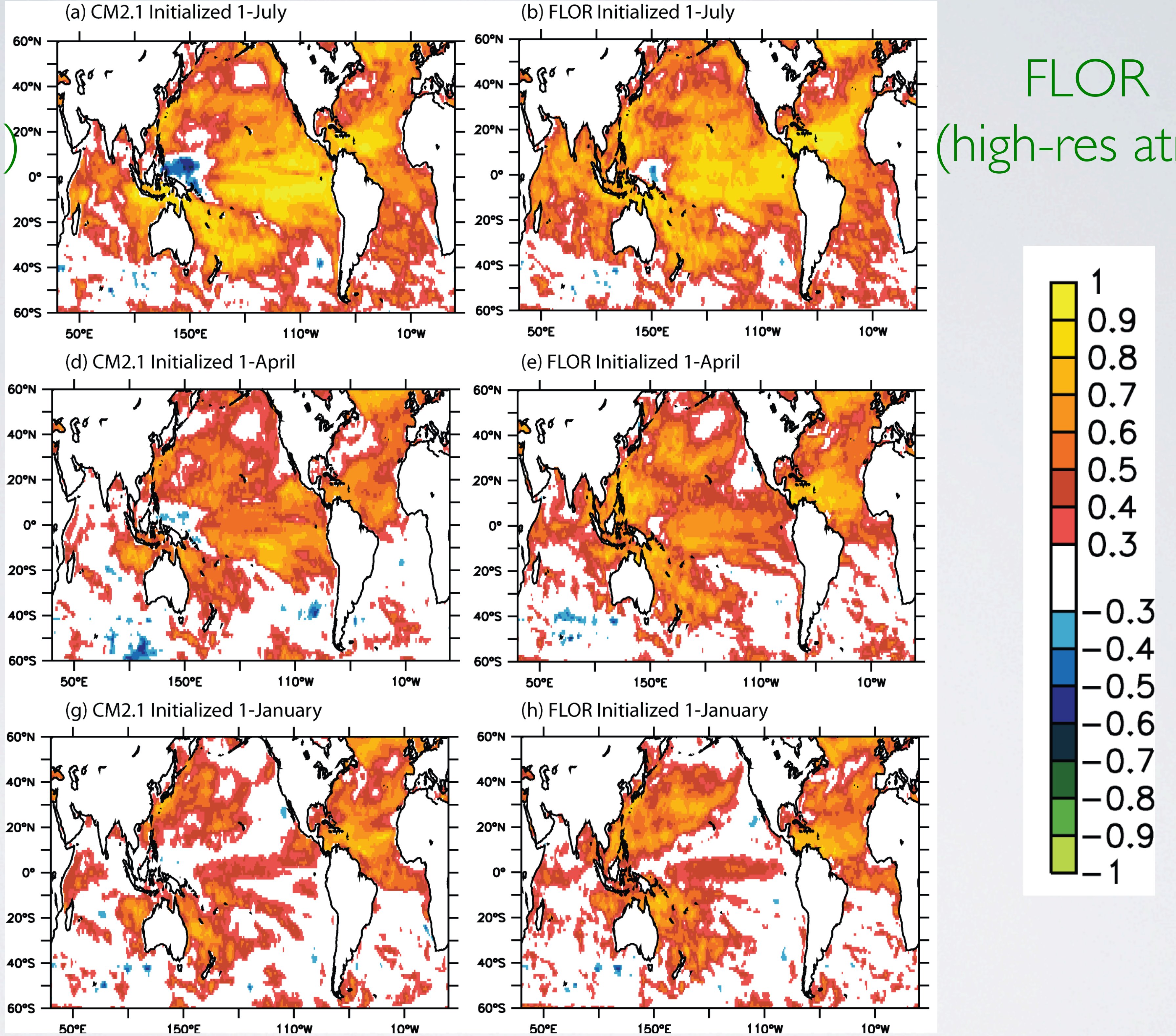
FLOR Improves on CM2.1 for SST Predictions



Retrospective predictions of ASO SST slightly improve in FLOR over CM2.1

CM2.1
(low-res atm.)

FLOR
(high-res atm.)



1981-2012 correl. of Aug-Oct SSTA predictions

Vecchi et al. (2014)

Multi-model ensembles

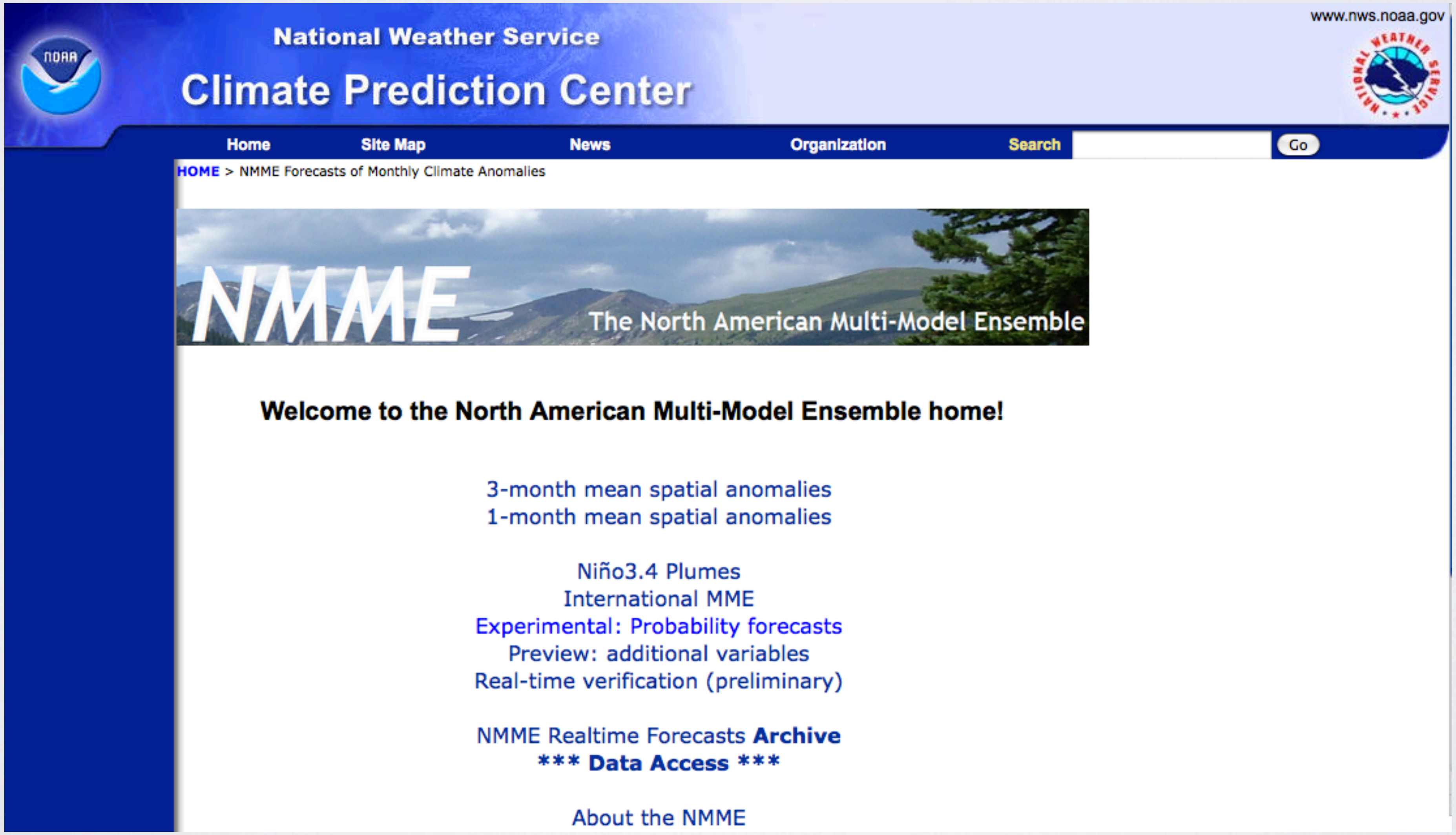
"Wisdom of the crowds"

- Many model errors differ across models
- Hypothesis: Looking across multiple models will:

1. Yield a more reliable prediction
2. More accurately represent true prediction uncertainty

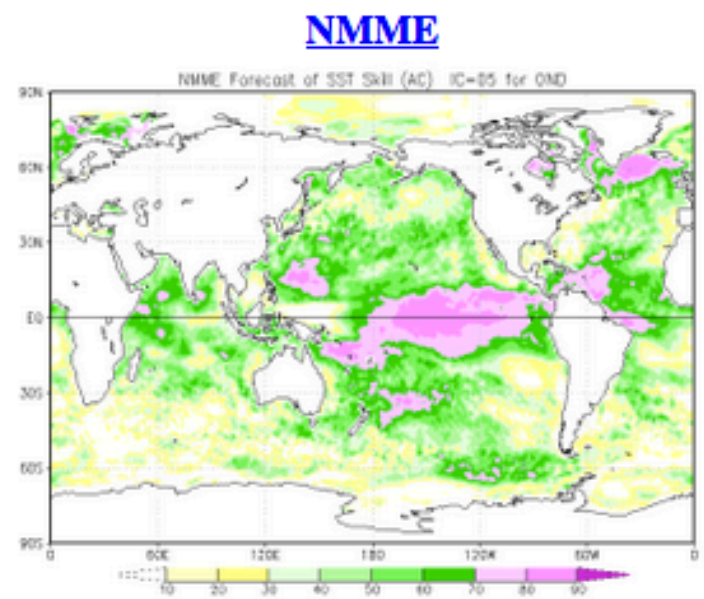
North American Multi-model Ensemble for Seasonal Prediction (NMME)

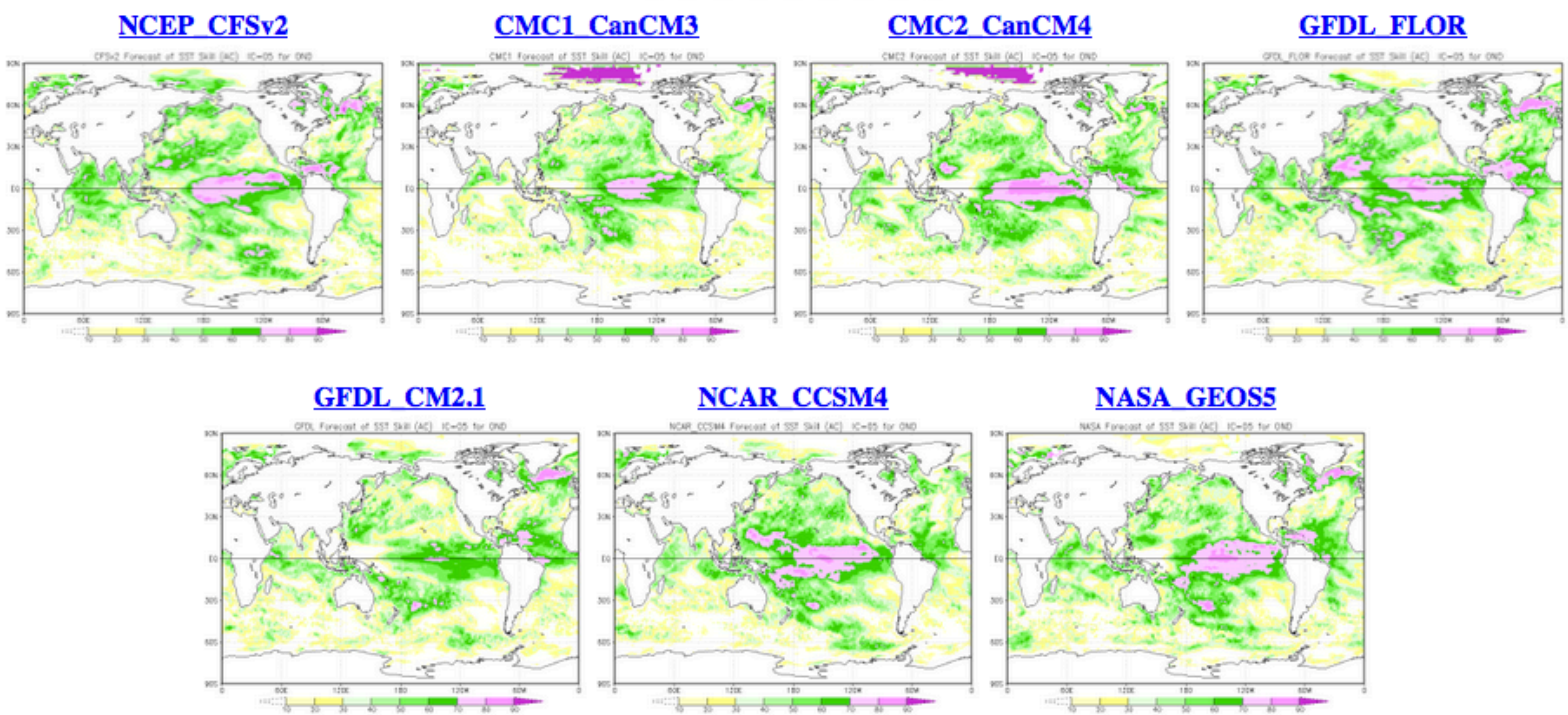
- NOAA-led, interagency (& international – U.S.A. & Canada) effort
- Every month predictions from multiple models combined.
- Data & analysis publicly available:
  http://www.cpc.ncep.noaa.gov/products/NMME/



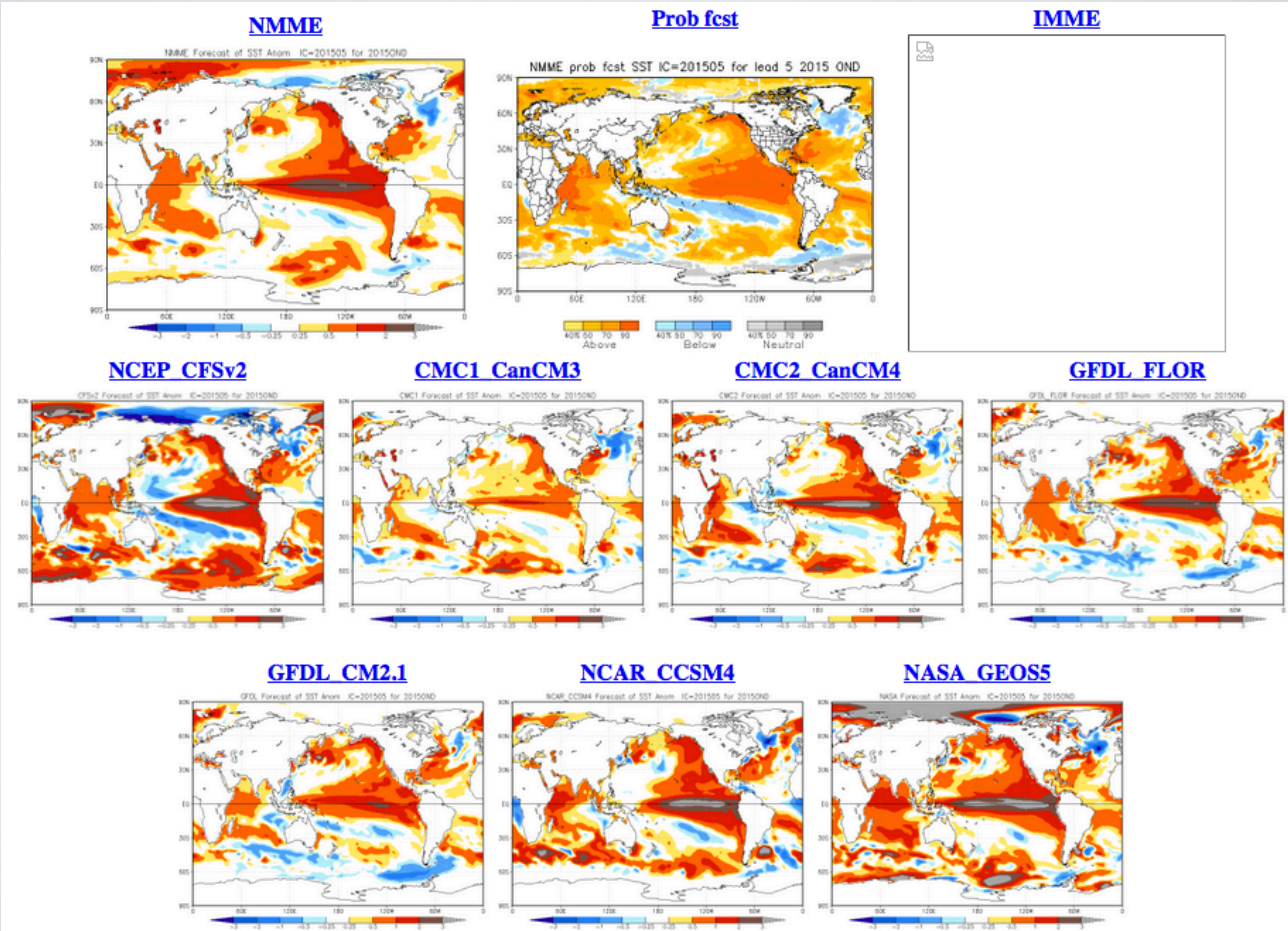
NMME tends to outperform individual models (OND SST forecast from 1-May)

Retrospective correlation





NMME prediction for OND 2015 SSTA – from 1-May



Summary

- Both changes in external conditions (e.g., CO_2, dust, volcanoes) and internal variations (e.g., El Niño, Overturning circulation) are basis for prediction.
- There are inherent limits to predictability:
need to think probabilistically in forecast production, use and evaluation
depend on scales and phenomena.
- Enhanced computing enables the development of high-resolution dynamical models.
- Multi-model techniques tend to yield more reliable predictions
- Errors in large-scale simulation a key source of biases in simulation/prediction of regional climate and extremes
- Partnerships and co-development can facilitate development of new prediction applications – and reduce risk of misuse of predictions